Evaluation of SAR Reduction for Mobile Phone Using RF Shield

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***Abstract*—This paper presents the numerical evaluation of the microwave absorption at 2.4 GHz (ISM band) in a homogeneous rectangular head model. Specific absorption rate(SAR) reduction in the head model is achieved by attaching nickel-zinc spinel ferrite sheet resonating at 2.4 GHz to a mobile phone. RF shields made of ferrite sheets are used to suppress surface currents on the mobile phone. Simulations are performed to investigate the effect of various parameters like size, shape and type of the shield on the SAR using CST-Microwave studio, the field simulation software. The SAR is obtained by calculating electric field strength at various points in the head model with and without RF shield. The E-field variation in the head model shows that RF shields reduce the SAR effectively. Numerical results are compared with experimental results from published work. Simulation results will be useful for compliance testing of mobile phones.**

***Index Terms*—SAR, SRF, Mobile phone, RF shield, Relative Permittivity and Permeability.**

I. Introduction

The widespread use of wireless communication devices that operate in the ISM band with close proximity to the human body remains a topic of growing public concern. It is desirable that the level of RF power absorbed in the human body does not exceed safety limits. Hence there is a need to develop techniques to reduce radiations from wireless devices for compliance testing [1].SAR reduction in a homogeneous rectangular head model was achieved by attaching nickel-zinc spinel ferrite sheet at 2.4 GHz (ISM band) to mobile phone [2].

The SAR is normally used to evaluate the degree of the hazard to the humans. Since live human heads can not be safely experimented for SAR measurements, computational RF dosimetry provides the best estimate of SAR in actual human heads [3]. The SAR in the human head is defined as follows.

$$SAR = \frac{\sigma|E|^2}{\rho} w/kg \qquad (1)$$

Where σ the electrical conductivity of tissue, E is *the* rms magnitude of the electric field strength vector at a given point in the head model, and ρ is the mass density of tissue. As per the FCC, ANSI/IEEE and Safety code 6 standards the recommended SAR values are 0.08 W/Kg for a Whole body and 1.6W/Kg for over any 1gram(g) of tissue.

While various absorbing materials can be used for making RF shields, ferrite absorbers are preferred because they are light in weight and do not cause degradation of the radiation pattern in the maximum direction of the radiation in both the planes. The effectiveness of the RF shielding can be specified in terms of an SAR reduction factor (SRF) and is defined as follows [4]:

$$SRF_{Total}(\%) = \frac{P_{abs} - P_s}{P_{abs}} \times 100 \qquad (2)$$

$$SRF_{1g}(\%) = \frac{SAR_{1g} - SAR_{1g,s}}{SAR_{1g}} \times 100 \qquad (3)$$

$$SRF_{10g}(\%) = \frac{SAR_{10g} - SAR_{10g,s}}{SAR_{10g}} \times 100 \qquad (4)$$

Where SRF_{Total} is the total SRF, p_{abs} is the power absorbed in the head model, p_s is the power dissipated in the RF shield, SRF_{1g} is SRF for lg peak SAR, SRF_{10g}, is SRF for l0g peak SAR, SAR_{1g} is 1g peak SAR(without RF shield), $SAR_{1g,s}$ is 1g peak SAR (with RF shield), SAR_{10g} is l0g peak SAR (without RF shield), and $SAR_{10g,s}$ is l0g peak SAR (with RF shield), respectively. Larger SRF value implies greater shielding effectiveness.

The complex relative permittivity and permeability values of RF shields are taken from graphs[5][6].Actual values are obtained by digitizing these graphs using trail version of Digitize It 1.5 Software(Digitizer).Digitized values are tabulated in Table II. Calculated values of σ_1 and σ_2 are also tabulated in Table II. Where $\sigma_1 = \omega\varepsilon_0\varepsilon_r''$ =Electrical conductivity, $\sigma_2 = \omega\mu_0\mu_r''$ = Magnetic conductivity. In this paper we compare the experimental results with numerical results by finite integration technique (FIT) method using CST-Microwave studio.

II. MATERIALS

A homogeneous model of the human head as shown in Figure1 to 5 was simulated by an acrylic rectangular box of dimensions 18x18x14 cm, with 1.5 mm thick walls, filled with NaCl solution to represent head tissue equivalent material. The depth of the solution in the acrylic rectangular box must be more than 80% to minimize the reflections from the upper surface [7][8].The mobile phone model made of a perfect electric conductor (PEC) and a λ/4 monopole (3 cm in length) mounted on it was placed below the head model and operated at 2.4 GHz and 0.50 W power level. The RF shield was placed on the mobile phone for assessing SAR reduction. Electrical properties of the RF Shielding material are as shown in Table I. Electrical properties of the acrylic rectangular box and the head tissue equivalent material are as shown in Table II.

Table I. Different types of RF-shields at 2.4 GHz [5] [6]

RF Shielding Material; *1mm-thick*	ϵ_r ,Relative Permittivity		μ_r ,Relative Permeability		σ ,Conductivity	
	Re	Im	Re	Im	σ_1	σ_2
M1	7.02	1.88	3.15	1.20	0.25101	35624.3
M2	11	0.1	1	3.38	0.01335	64047.9
M3	11	0.1	1.31	2.67	0.01335	50594.0
M4	12	0.2	2.01	2.79	0.02670	52867.9
M5	12	0.2	2.07	0.64	0.02670	12203.6

Table II. Summary of dielectric parameters [7]

Material	ε_r	μ_r	σ (s/m)	ρ Density (g/ cm^3)
Air	1	1	0	1
Simulating muscle tissue at 2.4 GHz	39.8	1	0.64	1
Acrylic rectangular box at 2.4 GHz	2.56	1	0	1.49
PEC				

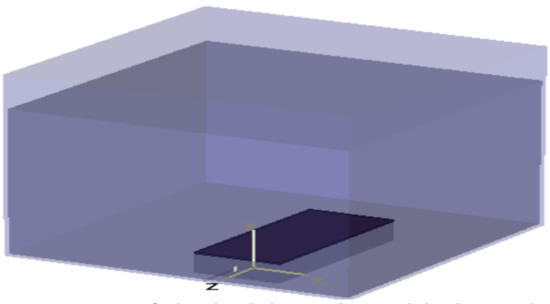

Figure 1.Exposure of a box head phantom by a mobile phone with full Size RF shield at 2.4 GHz.

The Nickel-Zinc spinel ferrites are preferred as microwave absorbers for portable wireless communication devices operating in the ISM band because they are compact, light weight, less costly, can be easily developed and do not cause degradation of the radiation pattern in the maximum direction of the radiation in both the planes. The purpose of this study was to determine the effectiveness of different ferrite materials and different shapes in the suppression of radiation.

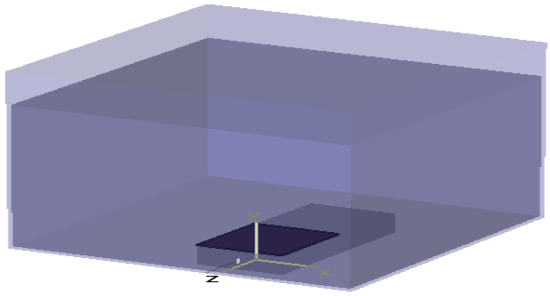

Figure 2.Exposure of a box head phantom by a mobile phone with half RF shield at 2.4 GHz.

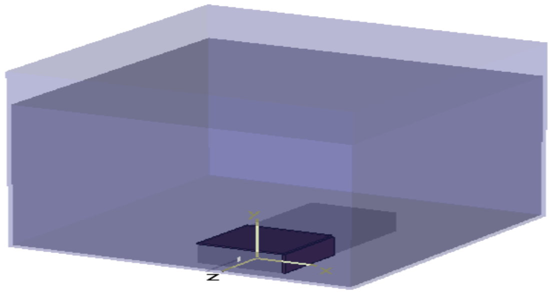

Figure 3.Exposure of a box head phantom by a mobile phone with L-shape RF shield at 2.4 GHz.

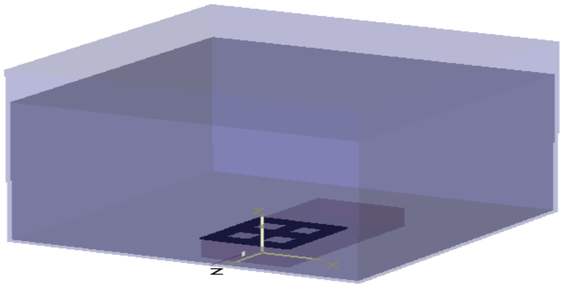

Figure 4.Exposure of a box head phantom by a mobile phone with mesh type RF shield at 2.4 GHz.

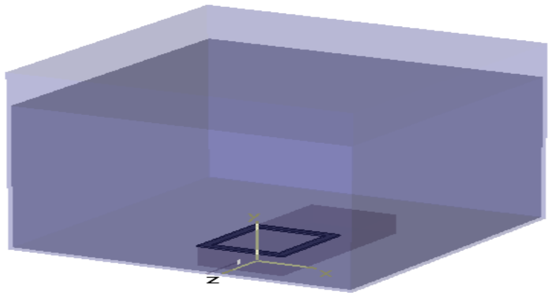

Figure 5.Exposure of a box head phantom by a mobile phone with window type RF shield at 2.4 GHz.

III. METHOD

The commercial field simulation tool, CST-Microwave studio was used to model RF shield, mobile phone and homogeneous rectangular head model for evaluating the SAR reduction [9], [10], [11], [12]. The basic parameters used for the simulation are as mentioned below:

The Perfect boundary approximation is used for spatial discretization. The mesh is produced by an automatic mesh generator, which ensures a good compromise between accuracy and simulation time. An ''add space'' boundary condition representing the electromagnetic wave propagating towards the outer space is set.

Mesh type	: Hexahedral;
Minimum mesh step	: 3.6;
Solver Type	: Transient solver;
Excited discrete port	: 1;
Reference impedance	: 50.0 ohms;
Steady state accuracy limit	: -30dB;
Number of processors used	: 01;
The antenna output power	: 0.5 watt (rms).

The antenna output power is defined as, $p_{out} = p_{abs} + p_s + p_{rad}$ where p_{abs} is the power absorbed in the head model, p_s is the power dissipated in the RF shield and p_{rad} is the power radiated to the far-field.

A. SAR reduction mechanism

Before deriving the SAR reducing effects using RF shield, the mechanism of SAR reduction is discussed [13]. The mechanism behind reduction of SAR is due to the suppression of surface currents on the mobile phone box. When an electromagnetic wave (EMW) traveling through free space encounters a different medium, the wave will be reflected, transmitted and/or absorbed. EMW absorption materials absorb the energy in electromagnetic waves as magnetic loss, and convert that energy, in the end, to heat. Current density on the mobile phone box is suppressed by putting RF shield on to it which in turn reduces the corresponding surface SAR in head model.

IV. NUMERICAL RESULTS AND ANALYSIS

The results discussed in this section are the effect of various parameters like size, shape, and type of RF shield on the SAR and SRF. Analysis is based on the results from Figure6 to Figure12 and Table III to Table V.

Table III contains peak SAR, Total SAR, Average Power, Power and SRF values simulated using various ferrites.M5 gives highest SRF (i.e. 56.74% reduction for 1g sample) followed by M3,M1and M4(56.09%,54.88 and54.42 % reduction for 1g sample respectively). M2 gives lowest SRF (i.e. 34.33 % reduction). Higher SRF indicates greater SAR reduction effect.

Similarly Table IV also contains peak SAR, Total SAR, Average Power, Power and SRF values simulated using various ferrite shapes. FS gives highest SRF (i.e. 54.88% reduction for 1g sample) compare to other shapes.

Table V shows comparison of simulation (present work) results with experimental results reported in the literature.FS among various shapes and M4 among various ferrites are found most effective in reducing E-Field.

Figure6 shows the average E-field variations along x-axis in the head model at offset of y=15, 20,25,30,35 mm. Graph shows that drastic reduction in E-Field is achieved for all ferrites.

Similarly Figure7 also shows the average E-field variations along x-axis in the head model at offset of y=15, 20,25,30,35 mm. Graph indicates that FS is most effective than other ferrite shapes in reducing E-Field.

Figure8 shows the E-field variation (not the average value) along x-axis in the head model at offset of y=20; 25 and 30 mm. For Without shield case graph indicates that E-field is maximum for an offset value of 20 mm and decreases with increase in offset value.

Figure9 shows that E-Field variation (not the average value) along x-axis in the head model at offset of y=20; 25 and 30 mm is drastically reduced with RF-shield. E-Field reduction is more in case of FS compare to HS ferrite. The E-field variations in the head model show that RF shields reduce the SAR effectively.

E-field probe was set to calculate the electric field at various points in y=constant plane(y=2.5 cm) in the head model with and without RF shield on the mobile phone. This data can be used to obtain SAR. The y-direction represents the depth inside the head model. Figure10 shows comparison of average E-Field values.E-Field reduction is maximum in case of Full shield.

Figure11 shows the average E-field variations along y-axis in the head model. Comparison shows that Full shield is most effective than other shapes.

Figure12 also shows the average E-field variations along y-axis in the head model. Comparison of average E-field variation is made between ferrite materials. M4 is most effective than other ferrite materials in reducing E-Field.

Table III. Peak SAR and SRF for different types of RF-shield (Full shield)

RF Shielding Material Type	ϵ_r		μ_r		Peak SAR (w/kg) 1g (rms)	Total SAR (w/kg) (rms)	Average Power [W/mm^3] (rms)	Power [W] (rms)	SRF (%) (1gm) (rms)
	Re	Im	Re	Im					
Without Ferrite[WF]	--	--	--	--	10.75	0.125609	1.25609e-007	0.440742	----
Materia1-1[M1]	7.02	1.88	3.15	1.20	4.85	0.0916732	9.16732e-008	0.321667	54.88
Materia1-2[M2]	11	0.1	1.00	3.38	7.06	0.079949	7.9949e-008	0.280529	34.33
Materia1-3 [M3]	11	0.1	1.31	2.67	4.72	0.0894468	8.94468e-008	0.313855	56.09
Materia1-4[M4]	12	0.2	2.01	2.79	4.90	0.0923479	9.23479e-008	0.324035	54.42
Materia1-5[M5]	12	0.2	2.07	0.64	4.65	0.0915228	9.15228e-008	0.32114	56.74

Table IV. Peak SAR and SRF for different shapes of RF-shield

RF Shielding Shapes of [M1]	€r		μr		Peak SAR (w/kg) 1g (rms)	Total SAR (w/kg) (rms)	Average Power [W/mm^3] (rms)	Power [W] (rms)	SRF (%) (1g) (rms)
	Re	Im	Re	Im					
WF	--	--	--	--	10.75	0.125609	1.25609e-007	0.440742	----
Full Shield[FS]	7.02	1.88	3.15	1.20	04.85	0.091673	9.16732e-008	0.321667	54.88
Half Shield[HS]	7.02	1.88	3.15	1.20	10.63	0.124095	1.24095e-007	0.43543	01.12
L-Shield[LS]	7.02	1.88	3.15	1.20	10.59	0.124051	1.24051e-007	0.435278	01.49
Mesh-Shield[MS]	7.02	1.88	3.15	1.20	10.71	0.124432	1.24432e-007	0.436611	00.37
Window Shield[WS]	7.02	1.88	3.15	1.20	10.72	0.12433	1.2433e-007	0.436254	00.28

Table V.Comparison of simulation (present work) results with experimental results reported in the literature [2].

Sr. No.	Particulars	Previous work [2]	Present work
1	Material used for mobile phone	copper	PEC
2	Material used for rectangular box phantom head	Fiber glass	Acrylic
3	Method	By measurements	FIT(CST-Microwave studio)
4	Effectiveness of RF shield at 2.4GHz	Full shield is better as compare to other shapes	Full shield is better as compare to other shapes
5	System used for the simulation/measurement	Signal generator, E-Field probe, voltmeter etc.	Pentium IV CPU,3.0 GHz Computer with 504 MB RAM OS: Windows XP-Ver.-2002
6	Effectiveness of average E-Field reduction using different ferrites at 2.4GHz	Not applicable	M4 is most effective than other ferrite materials in reducing average E-Field.

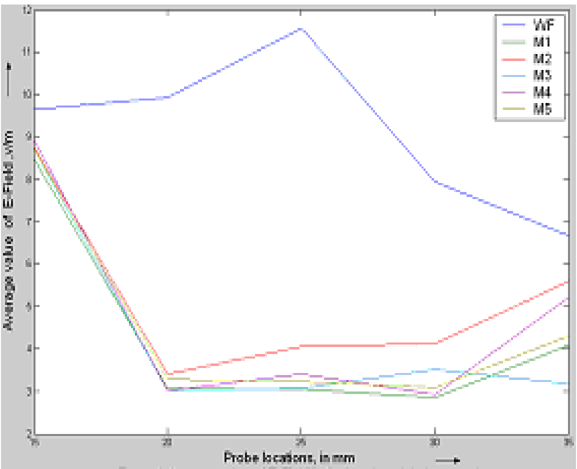

Figure 6. Average value of E-Field in the head model along x-axis.

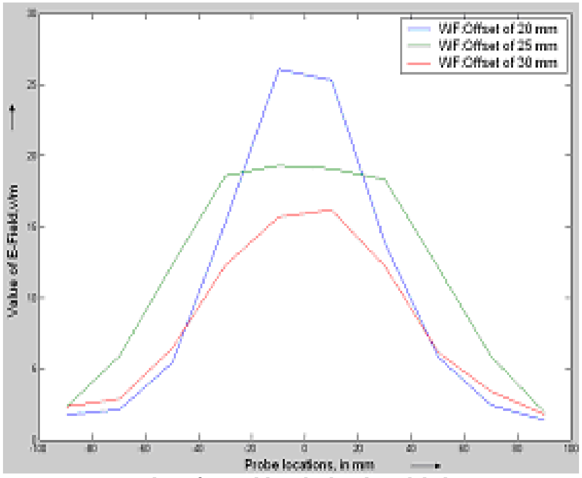

Figure 8. Value of E-Field in the head model along x-axis

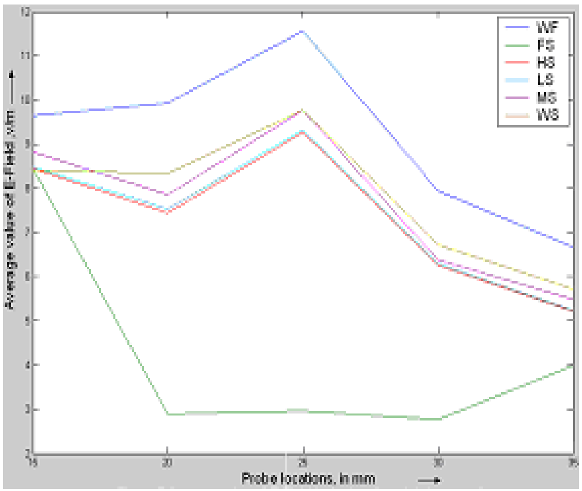

Figure 7.Average value of E-Field in the head model along x-axis.

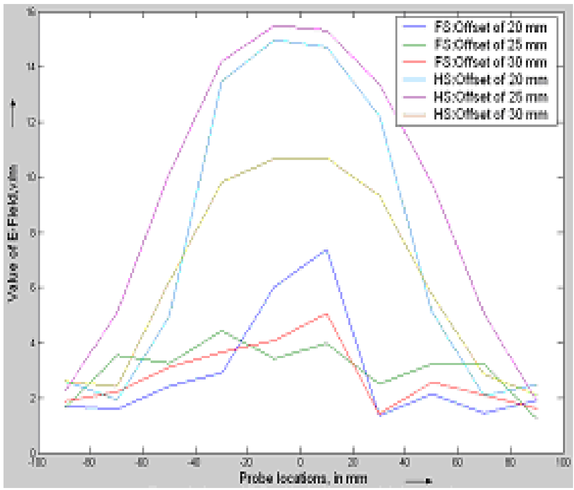

Figure 9.Value of E-Field in the head model along x-axis.

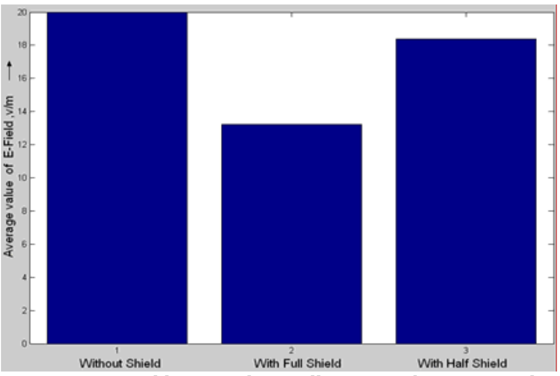

Figure 10. E-Field averaged over all points in the y=2.5cm plane

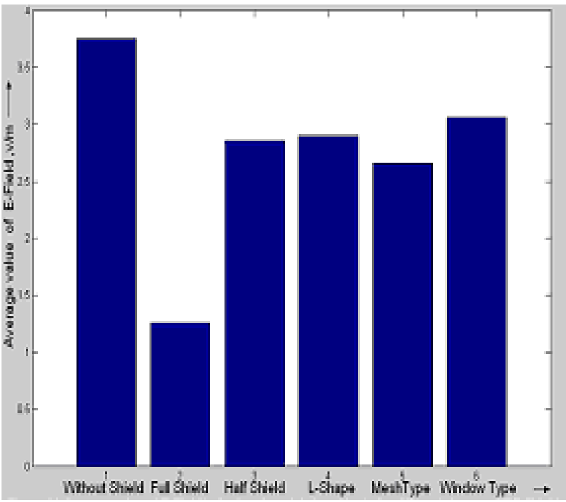

Figure 11.Average value of E-Field in the head model along Y-axis for different shapes of RF Shield.

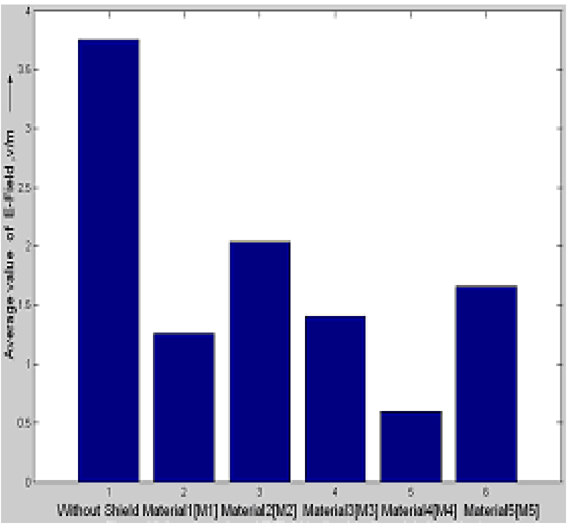

Figure 12.Average value of E-Field in the head model along Y-axis.

V. CONCLUSIONS

In the present study simulations are carried out using CST-Microwave studio. Results indicate that Full shield among various ferrite shapes and M4 among various ferrites are most effective in reducing average E-Field. The E-field variations in the head model show that RF shields reduce the SAR effectively. More than 54 % SRF is achieved by all ferrites except M2 for 1g sample. M2 gives lowest SRF (i.e. 34.33 % reduction). Higher SRF indicates greater SAR reduction effect.

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